^{39}Ar-^{40}Ar AGES OF IGNEOUS NON-BRECCIATED EUCRITES. D. D. Bogard and D. H. Garrison[1], Planetary Sciences, SN4, NASA Johnson Space Center, Houston, TX 77058 ([1]also Lockheed-Martin ESS; bogard@snmail.jsc.nasa.gov).

Introduction and Background: Sm-Nd, Pb-Pb, and Rb-Sr isochron dating of a few eucrites and eucritic clasts in howardites indicate that formation of the HED parent body (possibly 4-Vesta; 1) and generation of basalt began ~4.56-4.55 Gyr ago. Some additional eucrites, however, give isochron ages in the range of ~4.40-4.54 Ga, and it has been suggested that younger ages for a few cumulate eucrites represent actual igneous formation times up to ~0.15 Gyr after HED parent formation. (See (2) and references therein) In a few cases, some short-lived chronometers also imply younger eucrite formation times (3). Two factors complicate the interpretation of radiometric formation ages of eucrites, however. First, many eucrites have been subjected to post-formation parent body metamorphism at some early unknown time, which caused cation diffusion and chemical equilibration of pyroxene (4). Second, essentially all brecciated eucrites were shock heated ~3.5-4.1 Ga ago, which partially or totally reset their ^{39}Ar-^{40}Ar ages. This impact age resetting is probably related to the cataclysmic bombardment of the moon (5). If any eucrites escaped K-Ar age resetting during the cataclysmic bombardment, then their K-Ar age would give a lower limit to the time of pyroxene equilibration and possibly constrain the cooling time of parent body metamorphism. The corrected ^{39}Ar-^{40}Ar age of 4.485 ±0.015 Ga for the unbrecciated and metamorphosed (but shocked) Ibitira eucrite places a lower limit to the time of any metamorphism (6).

New ^{39}Ar-^{40}Ar data for Caldera and EET90020 eucrites: Caldera is unbrecciated, contains no vesicles, and its pyroxene suggests prolonged annealing (7). From one PTS, EET90020 was described as unbrecciated and strongly metamorphosed, but possessing an igneous texture. A combination of features considered unique among eucrites (8). Except for the absence of shock, EET90020 resembles Ibitira. However, when we examined EET90020 in the curatorial facility, we observed that approximately half of the meteorite appeared brecciated and half unbrecciated and that the area between the two portions contained several deep, interconnecting voids, some of which were lined with dark, thick glass. We made ^{39}Ar-^{40}Ar analyses on samples from both the brecciated and unbrecciated areas and of the dark glass. No chronological data have been reported previously for EET90020.

Figure 1 shows ^{39}Ar-^{40}Ar ages and K/Ca ratios as a function of ^{39}Ar release for stepwise temperature degassing of three of these four eucrite samples. The Ar release profiles and K/Ca ratios are nearly identical for the brecciated and unbrecciated samples of EET90020. Unbrecciated sample 22 shows only a small amount of diffusive loss of ^{40}Ar at low temperatures. It gives a constant ^{39}Ar-^{40}Ar age of 4.482 ±0.006 Ga across nine extractions and ~85% of the total ^{39}Ar release (omitting the lower age for the extraction at ~83% ^{39}Ar release, which coincides with onset of degassing of a separate phase with lower K/Ca and which may include an ^{39}Ar recoil effect). Age uncertainties are 1σ and include uncertainties in all corrections (measurement, blank, decay , and reactor) and in the irradiation constant, but not an ≤0.5% uncertainty in the age of the hornblende fluence monitor. The Ar-Ar age for brecciated sample EET90020,26 shows slightly larger amounts of diffusive loss of ^{40}Ar. Nevertheless, six extractions of this sample releasing 65% of the total ^{39}Ar give an age of 4.489 ±0.002 Ga, nearly identical to the age of the unbrecciated sample. Two possible explanations for the near identity of these ages are either that negligible ^{40}Ar degassing occurred at the time of brecciation, or that the unbrecciated sample was also degassed by the brecciation event. Given the lack of observed shock effects in the unbrecciated portion of EET90020 (8), we prefer the former explanation. Neither EET90020 sample experienced significant degassing later than ~4.48 Ga ago.

^{39}Ar-^{40}Ar data (not shown) for a glass sample taken from an interior void of EET90020 contains large amounts (6 x10^{-5} cm^3/g) of terrestrial ^{40}Ar and an overall ^{40}Ar/^{36}Ar ratio of 308. Apparent Ar-Ar ages (when corrected for air-Ar) are variable and generally fall in the range of 1-2 Ga. We conclude that the glass lining these interior voids is not impact glass, but rather surface material that melted and invaded these voids during atmospheric entry. Measured K concentrations of EET90020 crystalline material and glass are both ~280 ppm, suggesting that K loss did not occur during melting of this surface material.

Our Caldera sample was significantly weathered, and the first few extractions released ~1.4 x10^{-6} cm^3/g of terrestrial Ar from a phase with substantially higher K/Ca, possibly consisting of weathered salts deposited on grain-surfaces. Using ^{36}Ar/^{37}Ar, the ^{39}Ar-^{40}Ar age spectrum (Fig. 1) has been corrected for a terrestrial Ar component released from this phase. Above ~17% ^{39}Ar release, however, Caldera gives an average age of 4.44 Ga. The last seven extractions releasing 60% of the ^{39}Ar define a plateau age of 4.46 ±0.03 Ga. The last two extractions, showing slightly lower K/Ca, suggest an age around 4.49 Ga. Although the plateau age for Caldera is slightly younger than those obtained for EET90020 and Ibitira, it is the same within its uncertainty.

Comparison of Ages: The Ar-Ar ages of Ibitira, Caldera and brecciated and unbrecciated phases of EET90020 probably all have similar values of 4.485 ±0.005 Ga (with an absolute age uncertainty somewhat larger). These ages are substantially greater than typical ^{39}Ar-^{40}Ar ages of ~3.5-4.1 Ga for brecciated eucrites and eucritic clasts in howardites. This indicates that these meteorites escaped the widespread cataclysmic bombardment resetting that apparently occurred on the HED parent body (5). An Ar-Ar age of 4.485 Ga is similar to Sm-Nd and Pb-Pb ages that have been reported for a few cumulate eucrites (e.g., 2) and to a ^{147}Sm-^{144}Nd isochron age of 4.46 ±0.02 Ga reported for Ibitira (9). However, an Ar-Ar age of 4.485 Ga appears younger than ^{147}Sm-^{144}Nd and Pb-Pb isochron ages for Caldera of 4.544 ±0.019 Ga and 4.516 ±0.003 Ga, respectively (10). Further, evidence from short-lived chronometers indicate that Ibitira is older than ~4.54 Ga (9). The unbrecciated portion of EET90020 is unshocked but substantially metamorphosed (8), whereas Ibitira is metamorphosed but also shows evidence of shock (4).

If we assume that EET90020 (and possibly Ibitira and Caldera) did not have their Ar-Ar ages reset by shock, then Ar-Ar ages of ~4.485 Ga must be explained by parent body metamorphism, possibly the result of slow cooling during deep burial as proposed by (11). Deep burial may also explain why EET90020, Ibitira, and Caldera escaped brecciation and K-Ar impact resetting. The fact that the K-Ar chronometer remains an open system at lower temperatures compared to other isotopic chronometers, in association with slow cooling at depth, may explain the younger K-Ar ages for igneous, unbrecciated eucrites compared to their likely formation times of >4.54 Ga.

References: (1) Binzel, *LPI Tech Rept. 96-02*, 1996; (2) Tera, Carlson, & Boctor, *GCA*, in press, 1996; (3) Nyquist & Bogard, *LPI Tech. Rept. 96-02*, 1996; (4) Takeda & Graham, *Meteoritics 26*, 129, 1991; (5) Bogard, *Meteoritics 30*, 244, 1995; (6) Bogard & Garrison, *GCA 59*, 4317, 1995; (7) Boctor, Palme, El Gorsey, & MacPherson, *Meteoritics 29*, 445, 1994; (8) Yamaguchi, Taylor, & Keil, *LPS XXVII*, 1469, 1996; (9) Prinzhofer, Papanastassiou, & Wasserburg, *GCA 56*, 797, 1992; (10) Wadhwa & Lugmair, *GCA*, *60*, 4889, 1996; Galer & Lugmair, *MPS 31*, A49, 1996; (11) Yamaguchi, Taylor, & Keil, *Icarus 124*, 97-112, 1997.